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Coal Mining at Moatize, Tete Province, Northwest of Mozambique: A Socio Environmental Analysis

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***Abstract* - The coal mining is since long time and nowadays a preponderant activity that favors a socioeconomic development from its energy matrix participation whose reflexes are being felt in the environment. This study was conducted to assessment socioenvironmental impacts of coal mining in Moatize Coal Basin, Northwest of Mozambique. Physical and chemical surface water analysis was conducted in Revúbuè, Moatize and Zambezi rivers and socioenvironmental diagnosis of resettled local communities took place in Cateme and September 25. Surface water samples were collected in 13 points during the rainy season, upstream and downstream of the rivers. Water parameters (pH, Eh, temperature, electrical conductivity and dissolved oxygen) were analyzed in situ by a multiparameter probe portable Model - HI 9828 HANNA. Turbidity parameters, STD, sulfates and metals (Al, As, Fe, Mg, Mn and Zn) were analyzed by (ICP/AES). The results were compared with the maximum permissible level (VPM) through Ministerial Decree 180/2004 of the Mozambican legislation and Brazilian Resolution CONAMA 357/05. They indicate changes in water quality: Revúbuè River presented VMP above the limit for Fe, Mg and OD with high concentration in 7 points. In the Revúbuè River tributary, VMP for STD was above the limit in 3 points. It also presented sulfates concentration above the VMP for 2 points. At the Moatize River pH is above the limit (> 9.0 in point P10) and values of Fe and Mg are higher than limit in four other points. The excess of Fe and Mg in water can cause harmful effects and deleterious in water organisms and consequently is impropriety for water supply to community. Changes are probably related to coal exploitation (that releases solids particulate and these percolate thrown into the rivers) and/or practices of subsistence. The socioenvironmental diagnosis has been elaborated from interviews with 116 aggregate families of local communities resettled. The interviews' results with communities indicate a moderate level of satisfaction (59%) with the implementation of the mine due to non-compliance of some social compensation, especially that unleashed conflicts with the mining (ground vibrations and noise) representing discomfort to those communities. The conflicts observed are: changes in traditional values and habits, deprivation of women of their traditional occupation means (agriculture) making them dependent; low fertility of agricultural fields in resettled village in relation to that ones they possessed; grazing areas are distant from their homes; structural problems with new houses (cracks and water infiltration). To local community the environmental monitoring in hydric bodies, dialogues with company and government and compensation payments are crucial for mitigate socioenvironmental impacts.**

Key – Words: Coal mining, socioenvironmental impacts, Moatize, Mozambique.

1. INTRODUCTION

The actual relations of man with the nature and its innumerous mineral activities of exploitation of mineral resources have contributed in some decisive way for the well-being and bettering of the quality of life of the present and future generations. Nevertheless, the excessive and decontrolled extractions have caused irreversible environmental damages as contaminations of toxic metals in soil and water.

In Mozambique, the mineral activity is practiced in industrial level in forms of megaprojects and artisanal through prospecting (SELEMANE, 2010). It is observed in Moatize region geologic conditions that allow a coal mining in open using *strip mining*, a classic method, contemplated to megaprojects. In this study three mining companies are highlighted: Vale S.A, Indian Consortium International Coal Ventures Limited – ICVL and Moatize Mines Ltda – that produce thermic and metallurgic coal. The highest point of coal exploitation was marked by the Vale (CRVD) activities in Mozambique initiated in 2004 and Rio Tinto in 2006. The implantation of those companies fit in the process of internationalization of big companies, in BRICS countries (Brazil, Russia, India, China and South Africa) intensified in the last decades (COELHO, 2015).

Tete Province, district of Moatize possesses one of the biggest coal reserves of the Permian age, deriving the Moatize Formation actually considered the biggest coal field province not exploited in the world. According to José & Sampaio (2012) the mine estimated reserves is over than 2.5 billions of tons which could be exploited in the next four decades. The exploration of coal by this companies is done in the coal field of Moatize where is located the Revúbuè, Moatize and Zambeze rivers, all important in the hydric supply to various activities, mainly to subsistence agriculture and artisanal fishery by the surroundings

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communities. The proximity of those mining companies to the riverbeds and consequently to communities that use that water as mean of survival and subsistence are subdue to a potential risk of exposure to toxic metals. In the other hand the implantation of the mining brought positive aspects and negatives impacts that configures as social conflicts.

According to Baird (2012), metals belong to a group of chemical elements with specific density and particular characteristics of toxicity. Constitute soils and rocks and can be found naturally in water or can be originated from the anthropic sources arising from the mining, domestic and industrial activities within others. According to Braga et al. (2005), water is one of the most important natural resources and highly used, being fundamental to life maintenance and existence. To the authors, quality of water is related to how to use it as intended, being contamination of the springs an impeachment for human supply. However, the hydric contamination associated to mining activities generates environmental discomfort and also problems of economic and social order, being necessary more studies to monitoring the quality of superficial water in Direct Influence Area (DIA) of mines.

In this context considering few studies about a possible contamination of superficial water by toxic metals in DIA of coal mines in Moatize, associated to importance that it represents to local population, this article focus on socioenvironmental impacts assessment arising of the coal mining, in relation to quality of superficial water and the conflicts generated by resettlement of communities that occupied the area of direct influence of mine.

2. MATERIAL AND METHODS

Physical characteristics of the study area

Mozambique is located at East Africa, presents around 780.000 km^2 of surface and 2.500 km shore line (MUCHANGOS, 1999). The study area is inserted in coal field of Moatize with about 8.455 km², in district of Moatize, Tete Province, northwest of Mozambique and is surrounded by three rivers: Revúbuè, Moatize, Zambeze and tributaries (Figure 1).

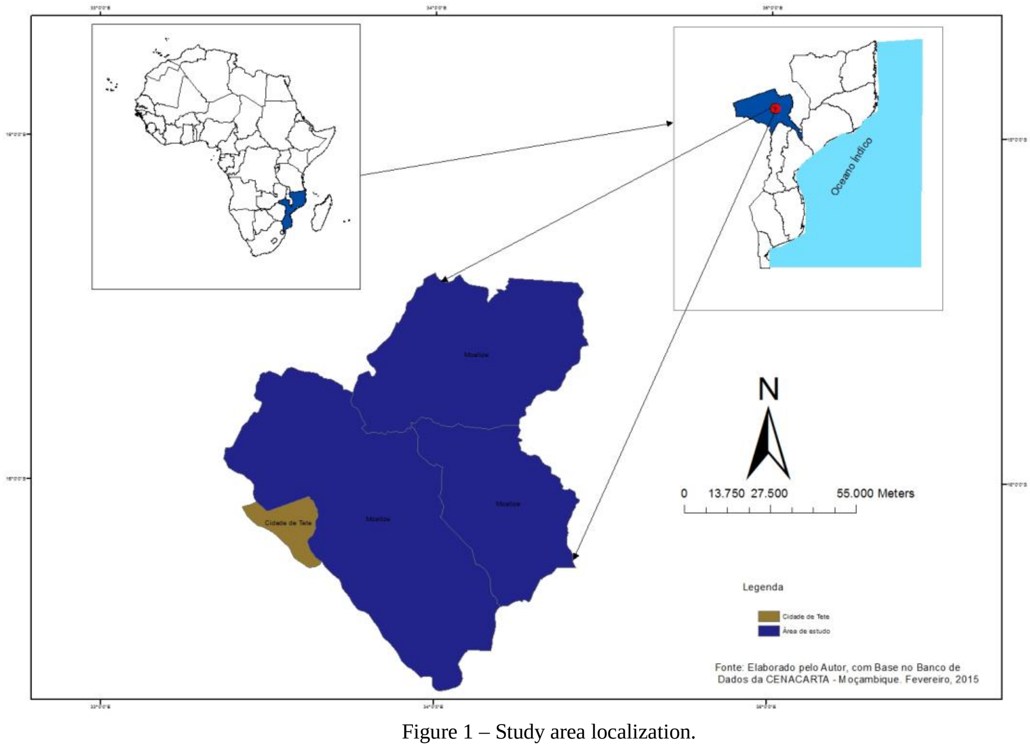

Figure 1 – Study area localization.

Moatize district presents two types of climate: dry climate of steppe with dry winter (BSw) in southern part of the district as Koppen classification, and the rainy tropical climate of savannah (AW) in the North part. The annual medium temperature is 26.5ºC with annual maxims of 40ºC. The higher precipitation occurs in summer (October – March), humid season with 800 mm annual. In dry season (April - September) in winter is registered a low precipitation with 644 mm annual. The annual medium potential evapotranspiration is 1626 mm (MAE, 2005).

The geology of Mozambique is divided by a crystalline base with the Archean-Cambrian age and a cover of rocks with the Phanerozoic age. This crystalline base is constituted by supracrustal metamorphosed paragnaisse, granulite and migmatites, ortognaisse and igneous rocks (CUMBE, 2007). According to GTK Consortium (2006b), Tete Province possesses a complex crystalline base divided by three different grounds: South, East and West Gondwana that collided and amalgamates during the Pan-African Orogenic Cycle. Therefore, the study area is inserted by whole in the South Gondwana ground that contemplate Zimbabwe Craton and a number

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of tectonics units in Proterozoic bend belts that were carried and deposited in top of the north and east margins of Mozambique characterized by rocks of Phanerozoic, mafic and felsic intrusions, the archaic belt of Manica (GTK Consortium, 2006a). The mineral coal of Moatize occurs with frequency in sediments of lower Karoo in most part deposited in Moatize Formation whose dispositional history began with the glaciations of the higher carboniferous age and ends with deposition of mixed clastic deposits of gross and fine granulation of Permian. In tectonic terms the Moatize formation fills a grabben that occupies an area of approximately 300 Km^2 between Moatize, Revúbuè and Murungodzi rivers (Figure 2) in northeast of Zambeze river oriented NW-SE and is surrounded by gabbros and anorthosites of Tete Suite from the Mesoproterozoic age (1600-1000 Ma). The NE limit of the basin is a normal fail of about 30 km of length oriented NW-SE and the SW limit is either by inconformity as well by contact of normal fail which is the case of M'pandi Mount. These fails define various sections and cuts vertically the basin hitting up to 100 m, originated by actions of extensive tectonic association to Rift of the East Africa that started to form during the early Jurassic (AFONSO, 1976 apud AMINOSSE, 2009).

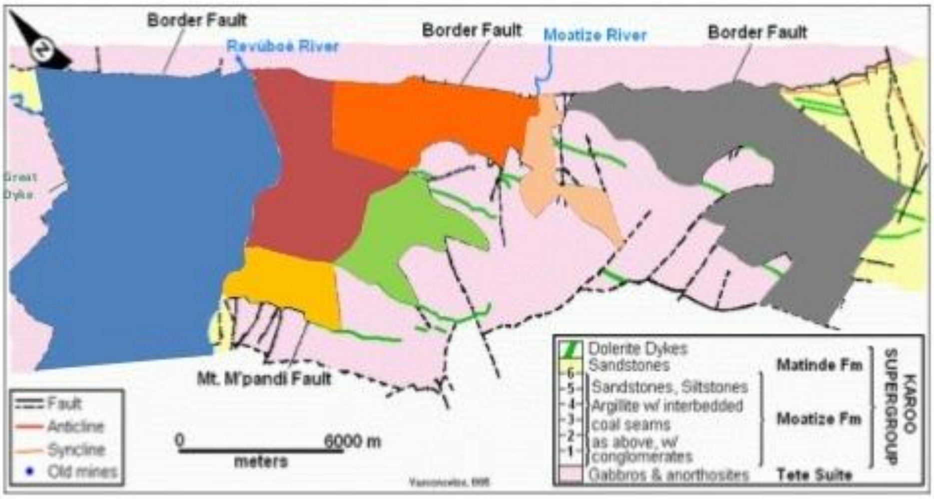

Figure 2 – Grabben of Moatize Formation, Tete Suite. Rivers studied are also represented (DNG, 2006).

The coal deposit of Moatize is constituted by rocks of sedimentary origin with corresponding lithologies as siltites and sandstones. The coal reserves are from type hula to bituminous and a productive series of Moatize basin represent a stratigraphic sequence constituted per six main coal layers designated from bottom to top: Andre Layer, Big Cliff Layer, Intermediate Layer, Bananeira Layer and Chipanga Layer (most important with 36m of thickness) and Sousa Pinto Layer (GTK Consortium, 2006d).

METHODS OF DATA COLLECTION

The methods of data collection comprehended three phases: bibliographic revision, work field and laboratorial analyses. Analysis of physico-chemical parameters and determination of metal presence in water are important tools to determinate the environmental quality of superficial water. A mapping of points with possible alterations of environmental quality due to multiple uses and soil occupation was make in field work. According to CONAMA (2005) & MISAU (2004), the standards of environmental quality favor protection to public health and control substances potentially harmful to man health as toxic metals, pathogenic microorganisms and radioactive elements.

The bibliographic revision has consisted in characterize coal mining in the coal field of Moatize considering regional geological framework. During field works superficial water samples were collected and subsequently were analyzed in laboratory. The results obtained were compared with the Mozambican environmental legislation, ministerial order nr 180/2004 and Brazilian by the CONAMA resolution nr 357 of 17 March of 2005.

SUPERFICIAL WATER SAMPLES

The water sampling was defined considering: land use and occupation, different types of geologic unities, and the distance of water drainage to coal mines and local communities. The environmental monitoring map of superficial waters (provided by Vale Mozambique Company) and the satellite images obtained by Google Earth Pro of Moatize district were used to define sampling points. In total 13 points were defined and samples were collected in Revúbuè, Moatize, Zambeze rivers and its tributaries (Figure 3). The samples were collected in a single period between January and February of 2015, rainy season in summer time.

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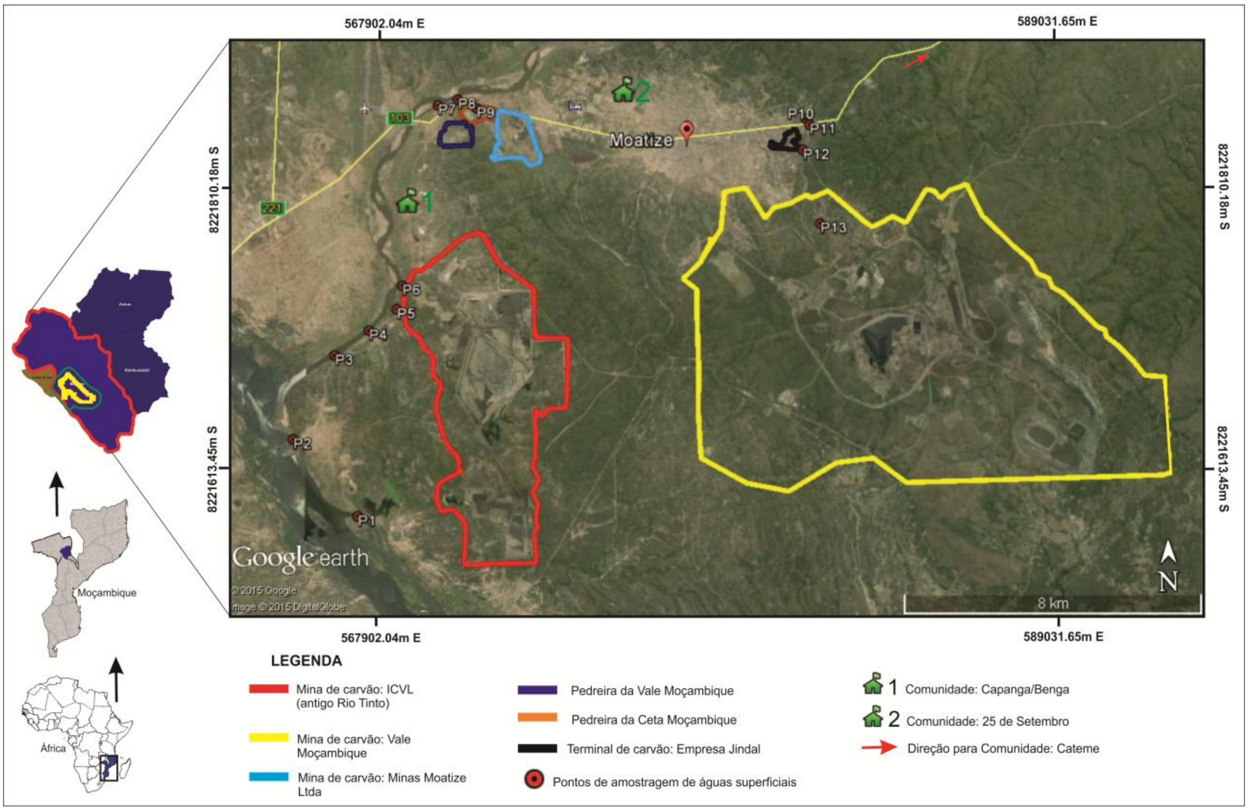

Figure 3 – Study areas location map showing superficial water collect points in Coal basin of Moatize (elaborated based on Google Earth Pro, 2015).

The physic-chemical parameters: hydrogenionic potential (pH) redox potential (Eh), temperature (T), dissolved oxygen (OD), electrical conductivity (CE) and dissolved oxygen (OD) were analyzed *in situ* through a portable multiparameter probe Model - HI 9828 HANNA calibrated before the field measurement with standards pH, CE and O_2. GPS Model Garmin 62s was used to georeferenced location points. Aquarel Lab Ltda Mozambique, specialized in water treatment situated in Tete municipality analyzed the turbidity, total dissolved solids, sulfates and chemical elements aluminum (Al), arsenic (As), iron (Fe), manganese (Mn), magnesium (Mg) and zinc (Zn) determined through an atomic emission spectrometer with inductively coupled Plasma (ICP/AES) made Spectro Analytical Instruments model FVM03. All standards cares were taken to collect water samples following the established in Standard methods for the examination of water and wastewater, in order to avoid possible contaminations that can interfere in the results (APHA, 2005).

The samples collected were performed with polyethylene bottles of 1.5l identified and previously washed in laboratories with hydrochloric acid 1:3 and distilled water, and rinsed three times before the definite collect. That collect was done with mouth-flask in contrary direction of the stream, in a ± 15 to 30 cm of depth in distance of 2 meters approximately in the margin of the river. Subsequently to analyze Al, As, Mg, Zn, Mg, the water samples were filtered with vacuum equipment and cellulose filter of 0.45 mm, and after acidified with nitric acid (HNO_3), kept in Styrofoam box with ice in a temperature of 4ºC together with others then taken in less than 24h to laboratory.

LOCAL COMMUNITIES RESETTLED BY VALE MOZAMBIQUE

Social conflicts were identified in local communities and data were collected using questionnaire submitted to leadership of each community resettled and the Mine Vale Mozambique manager. 116 family units randomly selected answered the questionnaire (Figure 4). This number represents 5% of the universe of 1.331 family units resettled by Vale Mozambique (Figure 3).

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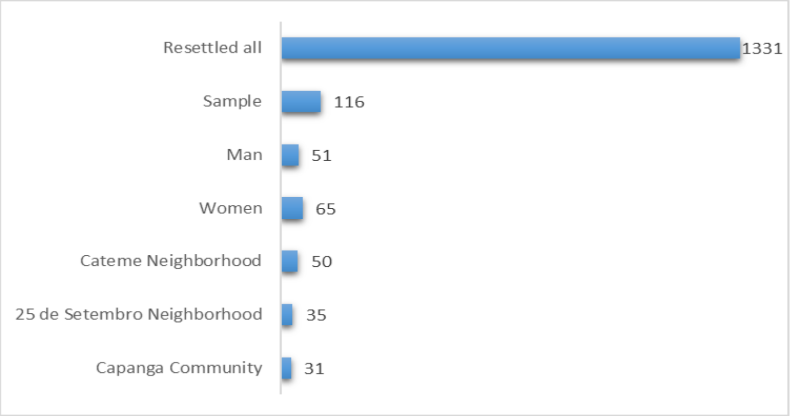
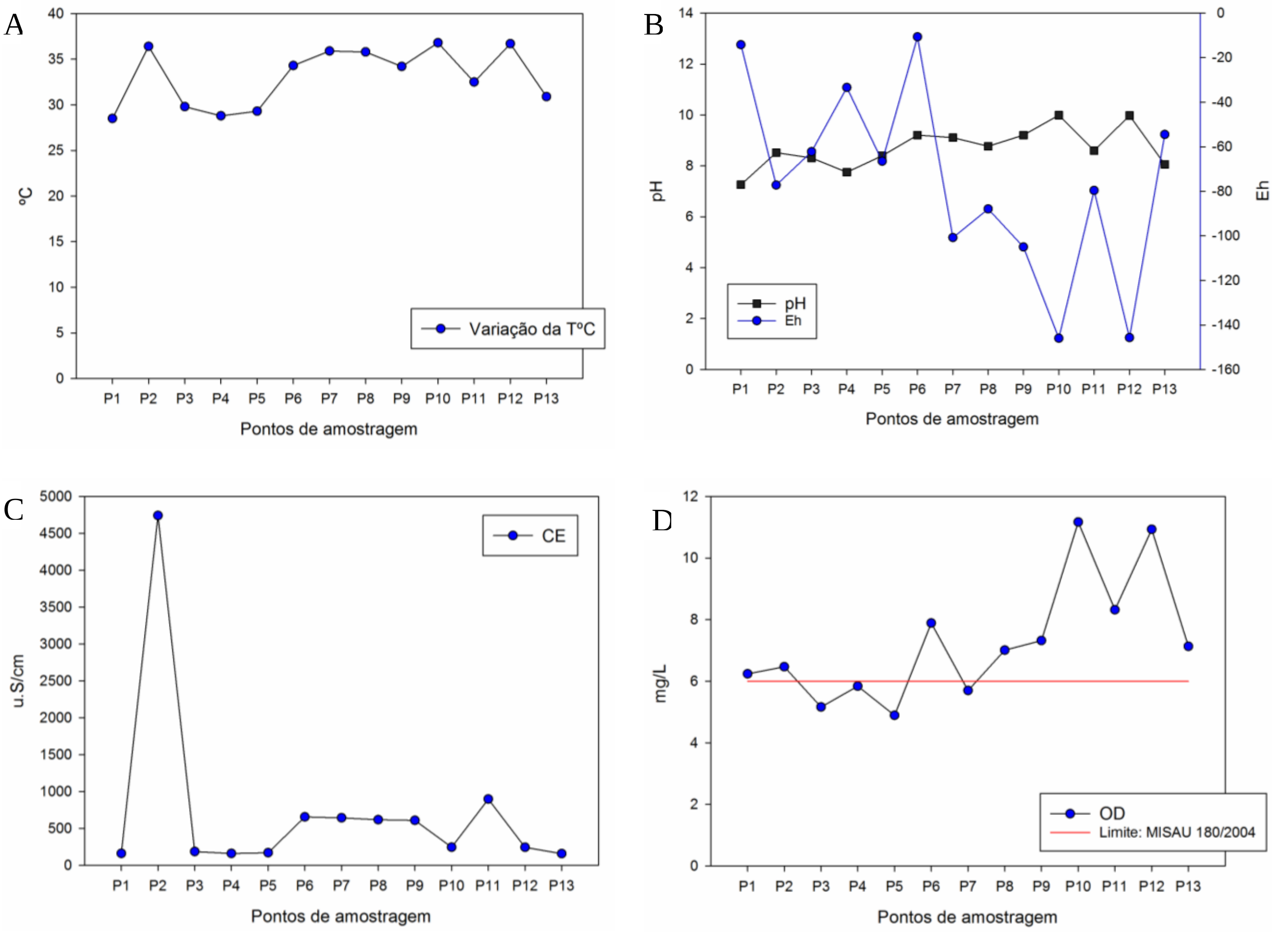


Figure 4 – Numbers of local communities interviewed.

3. RESULTS AND DISCUSSION

Physic-chemical superficial water analyses

The presented results were compared mainly with Mozambican legislation through Ministerial order nr 180/2004 that approves the regulation of quality of water for human use Part B – water intended to human use provided by sources of public supply without treatment, this law is regulated by Ministry of Health (MISAU, 2004). Also for some elements not foreseen by Mozambican Legislation was chosen the CONAMA resolution nr 357, of 17 de march of 2005 for freshwater class 2 of Brazilian legislation, regulated by Conselho Nacional do Meio Ambiente (CONAMA). The measurements *in situ* of following physic-chemical parameters: pH, Eh, TºC, CE and OD indicate that some values are out of standards proposed by Mozambican Legislation (Figure 5).



Figures 5. – Results of physic-chemical measures of parameters *in situ*: temperature (A), hydrogenionic potential and redox potential (B), electrical conductivity (C) and dissolved oxygen (D).

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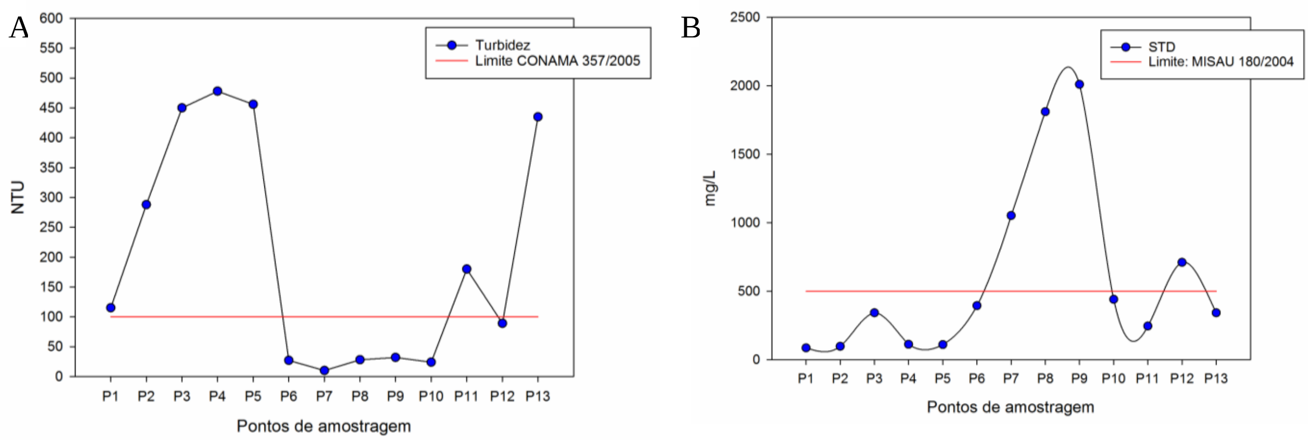
From the results showed in figure 5A it is possible to observe variation in T (ºC) of water registered in showed points. The P10, located near the terminal of Jindal company coal and an urban area of Moatize village in Moatize river, presented the highest temperature (36.8ºC) and the P1 near the Capanga community in Benga, at Zambeze river, registered the lowest temperature (28.5ºC). According to Apha (1995), the high values of T are extreme important, because with elevation of the temperature raise chemical and biological reactions and decrease gas solubility, as dissolved oxygen. To consider the analysis of physic-chemical parameters is important although its limits are not established in CONAMA resolution nr 357 and Ministerial Order nr 180/2004. Therefore, its importance is linked with an influence on biological process and chemical reactions in metabolism of aquatic organisms and disclosure of oxygen in water.

The pH determines the capacity in attacking some precipitated minerals being able to leachate its constituents. The Eh determines the form how an environment can produce oxidation and reduction reactions. Therefore, these two elements are related: higher the Ph, lower will be the Eh. All results of Ph are in Figure 5B. P1, P2, P3 and P4 the values presented low values due to dissolved sulfate in water which sources are probably related with family farming and suspense solid particles coming from the coal mine of ICVL Ltda., located in the surroundings of those points. From P5 to P13 there is a raise of values of pH and subsequently the values are lower for Eh. The P10 presented a high pH (9,99) and the lowest was registered at P1 (7,26), this area is situated in the proximities of the coal mine of ICVL Ltda. Comparing the medium value of pH (8,8) in all showed points it was observed that it is out of limits (6 to 8,5) according to Ministerial order nr 180/2004. From the 13 points analyzed 8 presented values above recommendations which is equivalent to 61.5%.

Electrical conductivity is the capacity of water to conduct electricity. This parameter is related with concentration of ions dissolved in water. The higher the concentration of ions higher is EC. The results obtained indicate that P2 (4,741 u.S/cm) at Zambeze river presented the highest EC values are in disagreement with the levels (50-2000u.S/cm) established at Ministerial order 180/2004 (Figure 5C). The agricultural activities and the influence of solid suspense particles of the coal mine of ICVL Ltda, probably percolated and dissolved in superficial water, are responsible for these values, considering the distance of sampling point.

Dissolved oxygen is one of the most important parameters in aquatic life favoring the respiration of all organisms. Its reduction is related to the presence of quantities of biodegradable substances in domestic and industrial waste. The results indicate that DO in most points presented values within the levels established at Ministerial order 180/2004 except P5 (4.89), a tributary of Revúbuè River, where values are below the legislation (Figure 5D). The presence of biodegradable organic substances coming from human resettlements of Capanga communities, with the vegetation quantities merged and suspense as probable substances coming from coal mine of ICVL Ltda due to superficial runoff can influence in DO. The average was 7.32 mg/L being a satisfactory value to hydric bodies.

Density turbidity is the water difficulty to transmit the light due to the presence of inorganic particles (sand silt and clay) and organic detritus as algae, bacteria which sources can be related with soil weathering conditions and rocks associated to river. The results indicated that the P2, P3, P4, P5, P11 and P13 presented levels above those established by CONAMA resolution 357/05 (Figures 6A and 6B). These high values are probably related to land use and occupation, resides charge due to sediment carriage by pluvial actions at those points.



Figures 6. - Results of turbidity (A) and Total Dissolved Solids (B) sampling analysis.

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The values of Total Dissolved Solids (TSD) vary between 86 mg/L at P1 to 2010 mg/L at P9. The results indicated high concentrations of TSD at P9, followed by P8 (1810 mg/L) and P7 (1052 mg/L) on the proximity of the coal mine of Moatize Ltda. and quarries of Vale Mozambique and Ceta. These values are out of the limit (500 mg/L) established for the Ministerial order 180/2004 (Figure 7A and 7B). Probably they are related with pluvial action where some substances are leachate and transported to the Revúbuè River. Therefore, Adôrno (2012) affirms that the high concentrations of TSD have negative consequences blocking the necessary light to photosynthesis process what compromises the base of food chain and environmental quality.

Heavy metals are toxic chemical elements when found in high concentrations and obviously harmful to human beings. Once ingested hardly will be not eliminated from the body, because they are accumulative substances. The *As* is one of toxic elements and carcinogen liberated by the coal combustion. The *Al* is present naturally in lower concentrations in superficial waters and usually is related to human activities. The *Mn* is related to leaching of rocks and soils as also the runoff in mines and industries that can render the concentration of that element (Baird, 2002). Therefore, results of the analysis indicate that the values of *As*, *Al*, *Mn* in all points are in accordance with the limits established on Ministerial order 80/2004 and CONAMA resolution 357/05 (Figure 7a). Samples P2, P10 and P11 presented higher concentrations of *As* although they do not exceed the limits of legislation. *Al* presented the higher concentration in P6 (Revúbuè River), probably due to human activities (agriculture and lack of basic sanitation at Capanga) and due to the proximity of communities to ICVL coal mine, that can influence a higher concentration of that element.

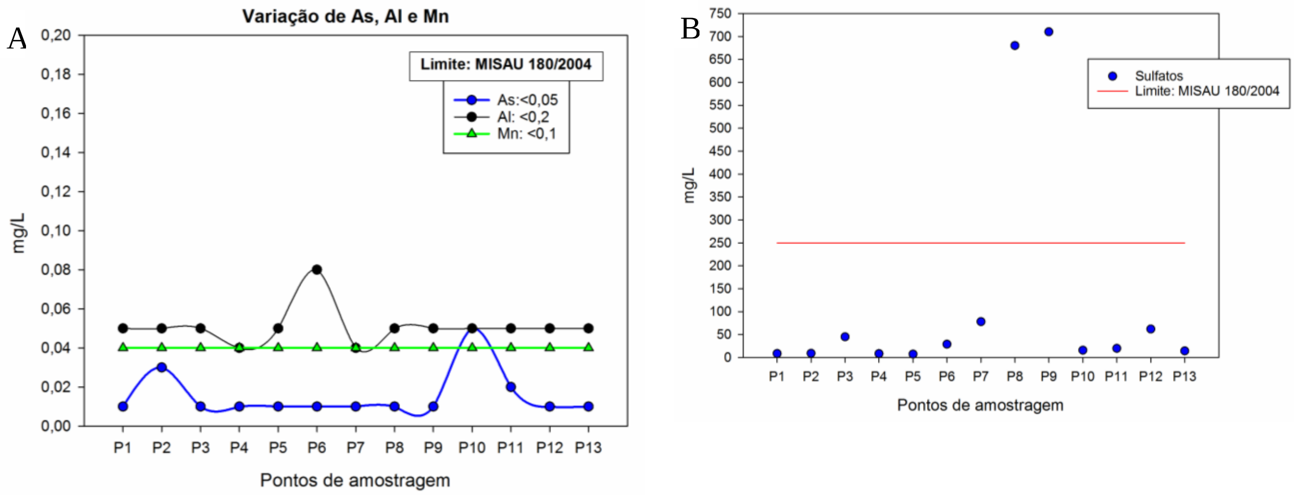

Figure7. – Results of heavy metals: As, Al, Mn (A) and sulfates (B) sampling analysis.

The principal origin of sulfates ($SO4^{2-}$) is the pyrite oxidation (FeS_2) considered one of the biggest problems of coal mining. It can also be originated by leaching of sulfated compounds (evaporites) as gypsum ($CaSO_4.H_2O$), anhydrite ($CaSO_4$) and by atmosphere precipitation due cyclic salts, continental and industrial dusts (GURGEL, 2007). The results indicated high values in P8 (680mg/L) and P9 (710 mg/L) at Revúbuè River. They are out of the limits established for the Ministerial order 180/2004 (Figure 7b). These high values probably are related to land use and occupation configured in coal mining by Moatize Ltda and quarries of Vale and Ceta Mozambique.

Fe is one of most chemical plentiful elements on Earth. The maximum values of *Fe* were observed in P12 (1.08 mg/L) - Moatize river and P13 (1.03 mg/L) -Vale Mozambique mine in Moatize River. These points are in surroundings of Jindal's coal terminal and Vale Mozambique mine. The results indicated that P3 (0.98 mg/L), P4 (0.4 mg/L), P5 (0.9 mg/L) P10 (1.03 mg/L), P12 (1.8 mg/L), and P13 (1 mg/L) presented values beyond maximum limits (≤ 0.3mg/L) established by the Ministerial order 180/2004 (Figure 8A). The *Mg* is one of the chemical elements that occurrence is rare, in general associated to carbonate rocks (VIANA, 2006). Samples from P7, P8, P9 and P12 presented values beyond the limits too (50 mg/L) as can we see in Figure 8B. *Zn* in most samples tends to concentrate below 0.04 mg/L (Figure 8C). To this element, all values are within the maximum limit (3.0 mg/L).

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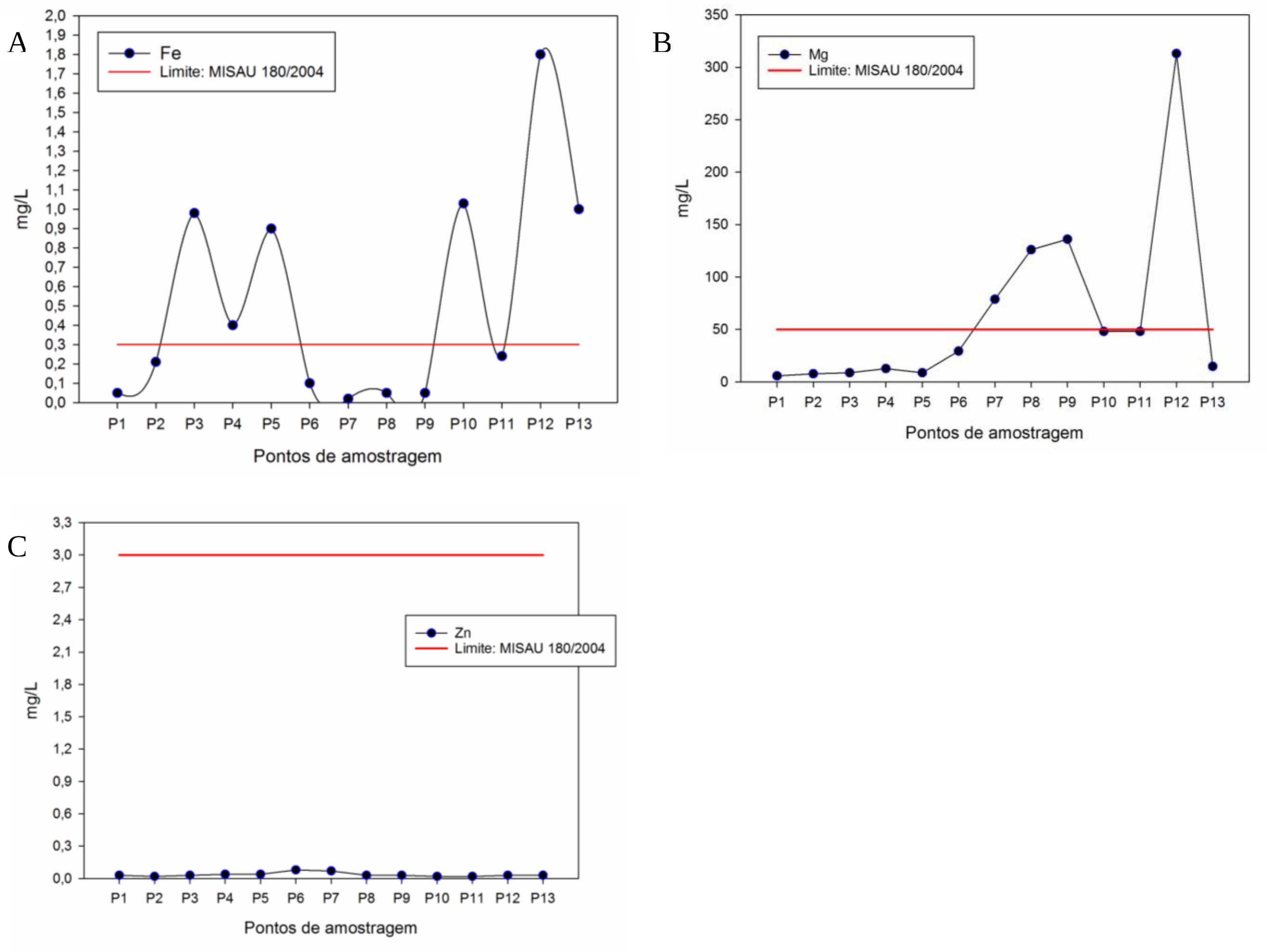
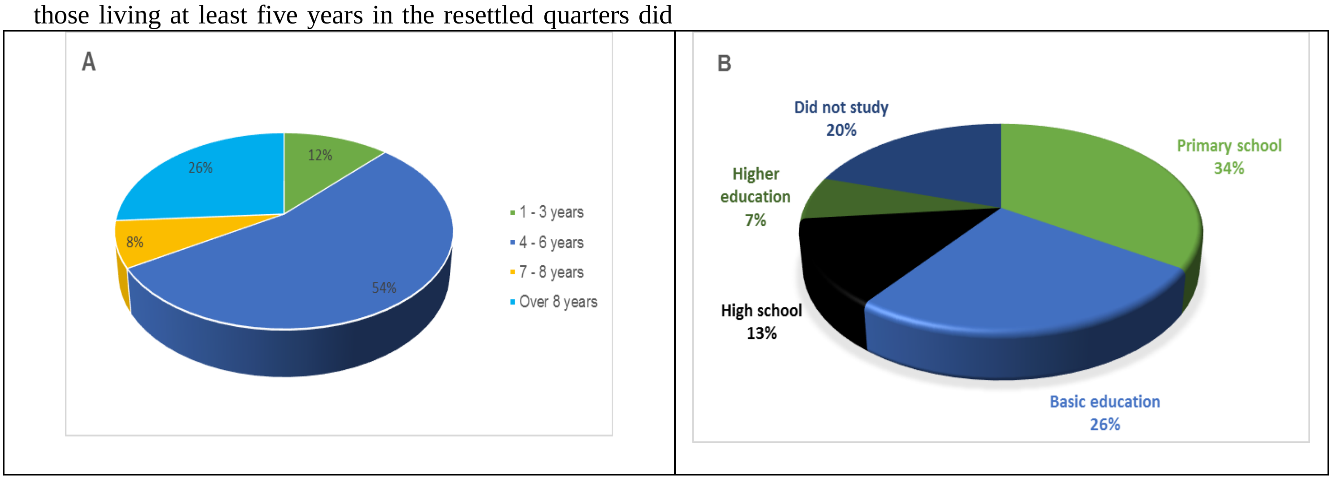


Figures 8 - Results of chemical elements: Fe (A), Mg (B) e Zn (C).

RESETTLED LOCAL COMMUNITIES SOCIO-ENVIRONMENTAL

The implantation of coal mining in Moatize district brought a new economic, social and environmental dynamic to the region (SELEMANE, 2010; MOSCA & SELEMANE, 2011). In terms of education grade 54% those living at least five years in the resettled quarters did not complete the basic level of education. 34% attends just primary level, 26% attends secondary level and only 7% attends university level. 20% of the community members did not attend school. In terms of professional activity 9% work in coal mines and the majority (33%) are landowners. 25% are unemployed (Figure 9).



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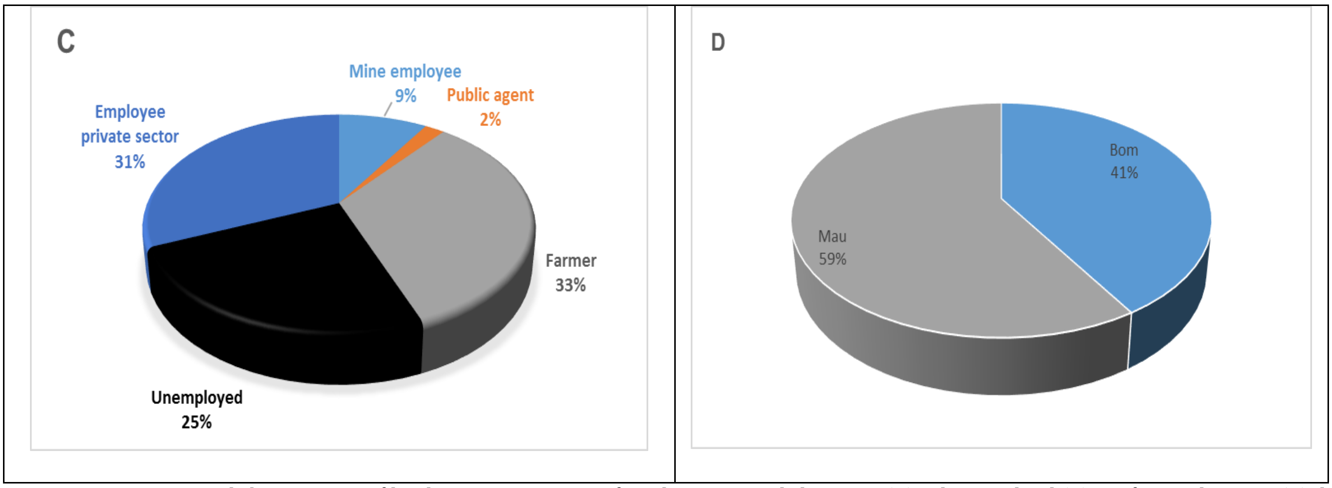

Figure 9 - General characteristics of local communities: time of residence in resettled quarters (A); education level (B); professional activity (C); local perception over the resettlement project (D).

In the interviews, members of local communities were inquired about their impression in relation to Vale Mozambique project. The majority answered that it had understood it is positive for the local socioeconomic development. The Moatize mine was officially inaugurated in May 2011 and the project was presented to community in a public audience. The project was initially well received by the local communities considering the benefits it would provide to the place. Over the following years, great part of the benefits was allocated to local communities but they are dissatisfied with the way the process was conducted, especially how the resettlement was executed. Fian (2010), Selemane (2010), Mosca and Selemane (2011) affirmed in their studies that some basic conditions promised were fulfilled and others considered important for the subsistence of communities were not, as example, transport to the District, alimentation support, good fertile agricultural field, what unleashed social conflicts. Nowadays the locals when questioned about their perception related to the Company they answered negatively. 59% of the resettled perceive the coal mining as a bad project (Figure 9D). They pointed out that the project brought problems to the communities in terms of social compensations that were not fulfilled: good water disposition, payment of compensations of the fructiferous trees, hand makers, insufficient transport.

The main environmental impacts and social conflicts raised by this research are: constructed habitation are not consistent, though be modern (notable fissures on walls and on the ground, water infiltration on the roof during rain season); ground vibration from blasting affect the residences and causes discomfort to the population; air pollution due to dusts raised in mining spcially in local plantations, generating contamination risks with toxic substances as SO_2, Hg, CO_2, CO, NO_2 present in vegetables; low fertility in the land destined for agriculture, dry soil and subsequently low capability of production related to the original areas the landowners had. The areas destined to cattle rising do not provide good conditions. The lack of payment of the promised social compensations is pointed as the big factor that endures the conflicts. ADECRU (2014) published that in April 2013, former landowners displaced by the mining project blocked the entrance to the mine. The company argued that it had paid approximately $2,000 per person, the landowners argued that they should receive more than that because of the loss of the community's brick-making industry.

The present research observed that the relationship community-company is not satisfactory. 64% of the inquired revealed discontent with Vale Mozambique mining due to violation of their rights.

4. SUMMARY

The results of physic-chemistry analyses of superficial water in the coal field of Moatize indicate alteration of water quality being that some values is in disagreement with the limits established in Mozambican Legislation, in ministerial order 180/2004 and Brazilian, CONAMA resolution 357/05. Therefore, the Revubue river presented high VMP for *Fe*, *Mg* and OD with the highest concentration at points P3, P5, P4, P9, P7 and P8. In tributary of Revúbuè river the VMP for STD has been above the limits at the points P9, P8, P7. Also values of sulfates are above the VMP at P9 and P8. In Moatize river the pH at point P10 presented value above the VMP (>9.0) and VMP above for *Fe* and *Mg* at the points P12, P10, P13 respectively. The excess of *Fe* and *Mg* in water can cause harmful effects and deleterious aquatic organisms and subsequently impropriety of water supply to human. The P7, P8 and P9 points in Revúbuè river at the surroundings of Moatize Mine Ltda. and the quarry of Vale and Ceta companies are signed as critical areas that needs an environmental monitoring due to their importance to public supply. So, waters of Revúbuè and Moatize rivers are not recommended to direct consume without treatment. However, the coal exploitation in Moatize by the mining Vale Mozambique, ICVL, probably do not have direct consequences up to now in the quality of superficial waters considering the showed points that can configure environmental impact, but some points presents alterations in water quality probably under influence of substances loaded or in suspension that percolate till reaches rivers originated from those mines.

The local communities present a law level of satisfaction with the implantation of the mine due to noncompliance of some social compensation especially the indemnity,that starts conflicts with the companies. As means to solve the conflicts the local communities points the following: payment of the indemnity, rehabilitation of habitats that present problems, integration of more local members in sectors that are related to mining work and creation of dialogue channel and mechanisms of participation including local members in decision process.

5. THANKS

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